

# CONTENTS

<b>LIST OF FIGURES</b>	<b>xxi</b>
<b>LIST OF TABLES</b>	<b>liii</b>
<b>PREFACE</b>	<b>lxxv</b>
<b>ABOUT THE EDITORS</b>	<b>lxxix</b>
<b>1. INTRODUCTION TO PLASTICS</b>	<b>1</b>
WORLDWIDE IMPORTANCE	1
PROPERTY AND BEHAVIOR	6
CHEMISTRY OF POLYMERS	10
Nanometer Polymer	30
MORPHOLOGY/MOLECULAR STRUCTURE/PROPERTY/PROCESS	30
Molecular Weight	31
Molecular Weight Distribution	33
VISCOSITY AND MELT FLOW	33
Newtonian and Non-Newtonian	33
RHEOLOGY	35
VISCOELASTICITY	35
PROCESSING-TO-PERFORMANCE INTERFACE	37
Glass Transition Temperature	37
Melt Temperature	37
CLASSIFYING PLASTIC	42
Thermoplastic: Crystalline or Amorphous	42
Liquid Crystalline Polymer	50
Thermoset	52
Cross-linked Thermoplastic	52

COMPOUNDING AND ALLOYING	54
INTRODUCTION TO PROPERTIES	54
PLASTICS CHARACTERISTICS	61
Thermal Behavior	63
Residence Time	65
Plastic Memory	65
Thermal Conductivity	67
Specific Heat	69
Thermal Diffusivity	70
Coefficient of Linear Thermal Expansion	70
Temperature Index	70
Corrosion Resistance	71
Chemical Resistance	71
Fire Property	72
Steel and Plastic	74
Permeability	74
Fluorination	74
Radiation	75
Craze/Crack	75
DRYING PLASTIC	75
VARIABILITY	79
ADVANTAGE AND LIMITATION	81
FALLO APPROACH	82
<b>2. PLASTICS PROPERTY</b>	<b>85</b>
OVERVIEW	85
PROPERTY RANGE	99
PLASTICS PERFORMANCE	111
HEAT-RESISTANT PLASTIC	111
THERMOPLASTICS	114
Polyolefin	115
Polyolefin Elastomer, Thermoplastic	115
Polyethylene	116
High-Density Polyethylene	126
Ultrahigh Molecular Weight Polyethylene	128
Polypropylene	130
Polypropylene Blends	133
Polybutylene	136
Vinyl	139
Polyvinyl Alcohol	146
Polyvinyl Butyral	146

Polystyrene	148
Polystyrene Film, Heat-Sealable	150
Syndiotactic Polystyrene	151
Polystyrene-Polyethylene Blend	151
Polystyrene-Polyphenylene Ether Blend	151
Acetal	152
Acrylic	152
Acrylonitrile	153
Cellulosic Polymers	156
Chlorinated Polyether	156
Ethylene-Vinyl Acetate	157
Ethylene-Vinyl Alcohol	157
Fluoroelastomer	157
Fluoroplastic	158
Ionomer	181
Nylon (Polyamide)	183
Parylene	189
Phenoxy	189
Polyallomer	191
Polyamide	191
Polyamide-Imide	191
POLYANILINE	195
POLYARYLATE	195
Polyarylester	196
Polyaryletherketone	196
Polyarylsulfone	197
Polybutylene Terephthalate	197
Polycarbonate	198
Polycyclohexylenedimethylene Terephthalate	200
Poelectrolyte	201
Thermoplastic Polyester	201
Polyester Thermoplastic and the Environment	201
Polyester-Reinforced Urethane	201
Water-Soluble Polyester	202
Polyetherketone	202
Polyetheretherketone	202
CHLORINATED POLYETHER	203
POLYETHERIMIDE	203
Polyethylene Naphthalate	204
Polyethylene Terephthalate	204

Polyhydroxybutyrate	207
Polyimidazole	207
Polyimide	207
Polyimide Powder	213
Polyesterimide	214
Polyketone	214
Poly lactide	215
Polyphenylene Oxide	216
Polyphenylene Sulfide	217
Polyphosphazene	217
Polyphthalamide	218
Polysulfide	218
Polysulfone	219
Polyethersulfone	220
Polyphthalamide	221
Polysaccharide	221
Polyterpene	221
Polythiophene	221
Polyurethane, Thermoplastic	221
Polyurethane Elastomer	222
Polyurethane Isoplast	222
THERMOSET PLASTIC	223
Alkyd	223
Allyl	229
Diallyl Phthalate	233
Epoxy	234
Epoxy Vinyl Ester	239
Ethylene-Propylene Elastomer	241
Fluorosilicone Elastomer	242
Melamine Formaldehyde	244
Neoprene	247
Phenol-Formaldehyde (Phenolic)	247
Polybenzimidazole	249
Polybenzobisoxazole	251
Polybutadiene	251
Polychloroprene	251
Polyester, Thermoset	253
Polyester, Water-Extended	258
Polyimidazopyrrolone	259
Polyisobutylene	259
Polyisobutylene Butyl	259

Polyisoprene	260
Natural Rubber and Other Elastomers	260
Polynorbornene	260
Polyurethane, Thermoset	260
Rubber, Natural	261
Rubber Latex, Natural	263
Silicone	265
Styrene-Butadiene Elastomer	271
Urea-Formaldehyde	272
ELASTOMER	273
REINFORCED PLASTIC	274
RECYCLED PLASTIC	278
Recycle Definition	309
PLASTIC SELECTION	311
Selection Approach	320
Chemical Resistance	322
Color	326
Crazing/Cracking	326
Elasticity	326
Electric/Electronic	328
Flame Resistance	328
Impact	328
Odor/Taste	331
Permeability	332
Radiation	338
Temperature Resistance	338
Transparency	360
Weathering	361
<b>3. FABRICATING PRODUCT</b>	<b>413</b>
OVERVIEW	413
Process	428
Classifying Machine	430
Complete Operation	436
Processing and Patience	436
Material and Fabrication Cost	438
Upgrading Plant	439
Processor Certification	440
PROCESSING FUNDAMENTALS	440
Melt Flow Analysis	441

Melt Strength	444
Melt Temperature	444
Newtonian Melt Flow Behavior	444
Non-Newtonian Melt Flow Behavior	444
Melt Flow Deviation	445
Melt Flow Rate	446
Melt Flow Performance	446
Melt Flow Defect	446
Melt Index	446
In-line Melt Analysis	447
Thermodynamics	447
MACHINES NOT ALIKE	449
MACHINERY PERFORMANCE	449
PLASTICS PROCESSING PERFORMANCE	450
Plastic Memory	451
Orientation	452
Directional Property	453
Plastic Deformation	453
Coextrusion/Coinjection: Fabricating Multilayer Plastics	456
PLASTICATOR MELTING OPERATION	457
SCREW	457
Design	461
Mixing	466
Shear Rate	466
Rate of Output	467
Shot Size	469
Screw Wear	469
Single-Stage Screw	469
Feeding Problem	470
Two-Stage Screw	473
Melt Degassing	478
Vent Bleeding	478
Length-Diameter Ratio	481
Compression Ratio	482
Pump Ratio	483
Transition	483
Screw Torque	484
Standard Screw	486
Marbleizing Screw	489
Mixing Device	489

Mixing Pin	490
Pulsar Mixing Screw	490
Union Carbide Mixer	491
Pulsar 11 Mixing Screw	492
Barrier Screw	499
Screw/Barrel Bridging	505
Screw Tip	505
Purging	514
Safety Alarm	515
Material of Construction	517
Multiple Screw	524
Recommended Screw Dimensional Guideline	531
Defining/Identifying Screw	531
BARREL	531
Barrel Composition	544
Injection Barrel	544
Extruder Barrel	544
Wear-Resistant Barrel	546
Corrosion-Resistant Barrel	547
Barrel Feed Throat	547
Barrel Grooving	548
Barrel Heating and Cooling Method	548
Barrel Temperature Override	551
Barrel Machining of Hole	552
Barrel Inspection	554
Barrel Borescoping	555
Recommended Barrel Dimensional Guideline	555
DOWNSIZING MACHINE	555
UPSIZING MACHINE	564
REBUILDING VERSUS BUYING	564
REPAIR	564
Screw Repair	565
Barrel Repair	566
STORAGE	568
TOOLING	568
PROCESS CONTROL	569
Overview	569
Sensor	572
Pressure Sensor	576
Temperature Sensor	577

Temperature Controller	579
Processing Window	579
Process Control and Patience	580
Process Control Trade-Off	580
Control and Monitoring	583
Process Controller	590
Intelligent Processing	592
PROTOTYPING MODEL	595
ENERGY	596
SAFETY	596
Machine Safety	596
Injection Molding Safety Issue	598
Safety Agency	603
<b>4. INJECTION MOLDING</b>	<b>605</b>
INTRODUCTION	605
MACHINE ELEMENT	610
MOLDING SYSTEM	612
Hydraulic	622
Fluid Power Basics	625
Electrical	626
Machine Capability	629
Summary	629
Hybrid	631
OPERATING CHANGE	631
Hydraulic to Electrical	631
CLAMPING DESIGN	633
Toggle	633
Hydraulic	636
Electrical	638
Hybrid	638
Tie Bar	640
Thermal Mold Insulation	640
PLASTICIZING	641
MACHINE CONTROL	644
DEVELOPING MELT AND FLOW CONTROL	646
Weld and Meld Line	650
MOLDING VARIABLES	659
Cooling	659
Shrinkage/Tolerance	667



Cooling/Cure Time	667
Tolerance/Fast Cycle	668
Mold Release	673
Recycling Plastic	679
MACHINE START-UP/SHUTDOWN	683
Maximizing Processing Window Control	690
Plastics Behavior	700
MACHINE DEVELOPMENT	705
COINJECTION MOLDING	705
LOW-PRESSURE COINJECTION FOAM MOLDING	706
GAS-ASSISTED MOLDING	706
GAS-ASSISTED WITHOUT GAS CHANNEL MOLDING	709
GAS COUNTERFLOW MOLDING	709
WATER-ASSISTED MOLDING	709
LOW-PRESSURE MOLDING	709
INJECTION-COMPRESSION MOLDING	709
TWO-SHOT MOLDING	710
IN-MOLD MOLDING	711
INSERT MOLDING	712
THIN-WALL MOLDING	712
SOLUBLE CORE MOLDING	714
CONTINUOUS MOLDING	715
TANDEM MACHINE MOLDING	715
MICROMOLDING	715
Overview	715
Summary	717
MONOSANDWICH MOLDING	718
DOUBLE-DAYLIGHT MOLDING	718
FOAMED GAS COUNTER PRESSURE MOLDING	718
HIGH-PRESSURE FOAM MOLDING	719
LOW-PRESSURE FOAM MOLDING	720
LIQUID MOLDING	720
COUNTERFLOW MOLDING	720
MELT FLOW OSCILLATION MOLDING	720
SCREWLESS MOLDING	721
NONPLASTIC MOLDING	721
Magnesium Molding	722
Thixotropic Molding	723
SUMMARY	723

<b>5. EXTRUSION</b>	<b>725</b>
INTRODUCTION	725
Extruder Basics	742
COMPONENTS	745
Extruder and Injection Barrel Compared	746
Drive System	747
Screen Pack	749
Gear Pump	753
Static Mixer	753
Heating and Cooling	754
Adapter	758
Barrel-Die Coupling	758
Die	759
Process Control	761
MACHINE DESIGN/PERFORMANCE	768
PLASTIC	771
EXTRUDER TYPE/PERFORMANCE	771
OPERATION	788
Start-up	788
Shutdown	796
EXTRUDER LINE	797
FILM AND SHEET	797
FILM	798
Blown Film	798
Flat Film	836
Film Winding	853
SHEET	858
Production	858
Auxiliary Equipment	870
Trim, Cut, and other Equipment	870
Laminating and Capping	873
Foam Sheet	875
PIPE AND PROFILE	878
PIPE AND TUBE	879
Die/Mandrel	879
Plastic	881
Extrusion Line	884
PROFILE	884
Die	893

COATING	900
Introduction	900
Production	903
WIRE AND CABLE	908
Production	911
FIBER	913
Overview	913
Fiber Definition	918
Production	918
Multifilament	922
Continuous Filament	922
Bulked Continuous Filament	924
Staple Fiber	924
Monofilament	924
Slit Film	925
Plain Tape	926
Fibrillated Tape	926
Air-Attenuated	926
Spun-Bonded	926
Melt-Blown	929
COEXTRUSION	929
Die	930
Plastic	933
Application	937
ORIENTATION	938
Introduction	938
Heat-Shrinkable	941
Plastic Behavior	941
Accidental or Deliberate Orientation	946
Production	947
Fiber	950
Other Processes	950
POSTFORMING	952
COMPOUNDING	954
Reclamation/Recycling	964
Pellet	966
EXTRUDER CLASSIFICATION	967
Horizontal/Vertical Extruder	971
Injection Molding/Noncontinuous Extruder	971

Ram Extruder	974
Disk and Screwless Extruders	992
SPECIALTY APPLICATION	992
Railroad Tie	992
Velcro Strip	993
Nonconventional Extruding	995
TROUBLESHOOTING	996
<b>6. BLOW MOLDING</b>	<b>1005</b>
INTRODUCTION	1005
Container	1009
Industry Size	1015
BLOW MOLDING PROCESS	1016
Blowing Requirements	1016
Airflow Control	1017
Extrusion versus Injection Blow Molding	1021
BASICS IN PROCESSING	1021
EXTRUSION BLOW MOLDING	1022
Extruder	1022
Melt Flow	1023
Parison Sag	1029
Parison Head	1034
Parison Wall Thickness	1035
Machine Design	1039
Single-Stage Design	1043
Two-Stage Design	1043
Continuous Extrusion Design	1044
Intermittent Extrusion Design	1046
INJECTION BLOW MOLDING	1063
STRETCH BLOW MOLDING	1071
Injection Stretch Blow Molding	1072
Special Machines	1084
Extrusion Stretch Blow Molding	1084
Dip Blow Molding	1085
Multibloc Blow Molding	1086
Other Blow-Molding Processes	1086
Blow Molding with Rotation	1095
MOLD	1097
Basic Features	1100
Materials of Construction	1101

Pinch-Off Zone	1101
Flash Control	1105
Blowing and Calibrating Device	1107
Venting and Surface Finish	1107
Cooling	1108
<b>PLASTIC MATERIAL</b>	<b>1113</b>
Blow Molding and Plastic	1120
Behavior of Plastics	1123
Barrier Plastic	1125
Barrier Material Type	1130
Blow Molding Reinforced Plastic	1130
<b>DESIGN</b>	<b>1131</b>
Bottle Design	1132
Industrial Products	1132
Complex Irregular Shape	1133
Oriented 3-D Parison	1135
Other Design Approaches	1136
<b>SUMMARY</b>	<b>1136</b>
History	1136
<b>7.THERMOFORMING</b>	<b>1141</b>
<b>INTRODUCTION</b>	<b>1141</b>
Process	1144
Growth	1146
Product	1146
<b>OPERATING BASICS</b>	<b>1147</b>
Forming Pressure	1151
Controlling Pressure	1152
Mold Construction	1154
Sheet Prestretch	1156
<b>PLASTIC</b>	<b>1159</b>
Overview	1159
Property/Performance	1163
Plastics Thermal Expansion	1164
Thermoforming Polypropylene	1166
Thermoforming Reinforced Plastic	1167
<b>HEATING</b>	<b>1167</b>
Heating Method	1173
Heat Control	1176
Heater Type	1177
Annealing	1177

COOLING	1180
Heat-Transfer Requirement	1181
EQUIPMENT	1182
Function	1189
MOLD	1190
Overview	1190
Detail	1191
Design	1192
Material of Construction	1194
PROCESSING	1195
Processing Phase	1199
Process Control	1200
Vacuum Forming	1200
Pressure Forming	1201
Vacuum/Air Pressure Forming	1203
Blow Forming	1203
Drape Forming	1204
Drape Vacuum Forming	1205
Drape Vacuum-Assisted Frame Forming	1205
Drape with Bubble Stretching Forming	1206
Snap-Back	1206
Plug-Assisted Forming	1206
Plug-Assisted and Ring Forming	1210
Ridge Forming	1210
Billow Forming	1211
Billow Plug-Assisted Forming	1211
Billow-Up Vacuum Snap-Back	1213
Billow Snap-Back Forming	1213
Air-Slip Forming	1214
Air-Slip Plug-Assisted Forming	1214
Blister Package Forming	1214
Draw Forming	1214
Dip Forming	1215
Form, Fill, and Seal	1217
Form, Fill, and Seal vs. Preform	1217
Form, Fill, and Seal with Zipper In-Line	1217
Multiple-Step Forming	1218
Matched Mold Forming	1218
Mechanical Forming	1219
Forging Forming	1219

Twin-Sheet Forming	1219
Cold Forming	1221
Comoform Cold Forming	1222
Shrink-Wrap Forming	1222
Scrapless Forming	1222
Forming and Spraying	1222
Postforming	1222
Bend Forming	1223
TRIMMING/SECONDARY EQUIPMENT	1224
DESIGN	1229
Overview	1229
Tolerance	1230
Plastics Memory	1231
TROUBLESHOOTING	1232
SUMMARY	1232
<b>8. FOAMING</b>	<b>1237</b>
OVERVIEW	1237
Basic Process	1242
Cell Configuration	1243
BLOWING AGENT	1244
Physical Blowing Agent	1246
Chemical Blowing Agent	1246
Thermoset Plastic Foam	1250
Water Foaming	1251
Chlorofluorocarbon and Alternate	1254
TYPE OF FOAM	1255
Structural Foam	1258
Reinforced Plastic Foam	1260
Acetal	1260
Acrylonitrile-Butadiene-Styrene (ABS)	1262
lonomer	1263
Phenolic	1264
Polycarbonate	1265
Polybutylene Terephthalate	1266
Polyetherimide	1269
Polyolefin	1269
Polystyrene	1273
Polyurethane	1280
Polyvinyl Chloride	1284

Other Foam	1289
Syntactic	1290
PROCESS	1295
Extruded or Calendered Foamed Stock	1298
Extruding	1299
Casting	1302
Spraying	1302
Frothing	1303
Expandable Polystyrene	1304
Expandable Polyethylene	1307
Expandable Polyethylene/Polystyrene	1307
Expandable Styrene-Acrylonitrile	1308
Molding	1308
Injection Molding	1309
Liquid Injection	1313
Structural Foam	1313
Foam Reservoir Molding	1314
Polyurethane Process	1314
Slabstock Molding	1318
Laminating	1327
APPLICATION	1329
Sheet and Film	1332
Polyethylene Cushioning	1334
Profile	1336
Strippable	1337
<b>9. CALENDERING</b>	<b>1339</b>
INTRODUCTION	1339
EQUIPMENT	1342
Roll Design	1343
Pressure on Roll	1351
Temperature	1353
Control	1355
Roll Disposition	1356
Downstream Equipment	1357
PLASTIC STOCK	1358
Compounding/Blending	1359
PROCESSING	1365
Market	1368
Calendering vs. Extrusion	1369